



■ HIP

Robotic arm-assisted versus manual total hip arthroplasty

A PROPENSITY SCORE MATCHED COHORT STUDY

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Aims

The primary aim of this study was to compare the hip-specific functional outcome of robotic assisted total hip arthroplasty (rTHA) with manual total hip arthroplasty (mTHA) in patients with osteoarthritis (OA). Secondary aims were to compare general health improvement, patient satisfaction, and radiological component position and restoration of leg length between rTHA and mTHA.

Methods

A total of 40 patients undergoing rTHA were propensity score matched to 80 patients undergoing mTHA for OA. Patients were matched for age, sex, and preoperative function. The Oxford Hip Score (OHS), Forgotten Joint Score (FJS), and EuroQol five-dimension questionnaire (EQ-5D) were collected pre- and postoperatively (mean 10 months (SD 2.2) in rTHA group and 12 months (SD 0.3) in mTHA group). In addition, patient satisfaction was collected postoperatively. Component accuracy was assessed using Lewinnek and Callanan safe zones, and restoration of leg length were assessed radiologically.

Results

There were no significant differences in the preoperative demographics ($p \geq 0.781$) or function ($p \geq 0.383$) between the groups. The postoperative OHS (difference 2.5, 95% confidence interval (CI) 0.1 to 4.8; $p = 0.038$) and FJS (difference 21.1, 95% CI 10.7 to 31.5; $p < 0.001$) were significantly greater in the rTHA group when compared with the mTHA group. However, only the FJS was clinically significantly greater. There was no difference in the postoperative EQ-5D (difference 0.017, 95% CI -0.042 to 0.077; $p = 0.562$) between the two groups. No patients were dissatisfied in the rTHA group whereas six were dissatisfied in the mTHA group, but this was not significant ($p = 0.176$). rTHA was associated with an overall greater rate of component positioning in a safe zone ($p \leq 0.003$) and restoration of leg length ($p < 0.001$).

Conclusion

Patients undergoing rTHA had a greater hip-specific functional outcome when compared to mTHA, which may be related to improved component positioning and restoration of leg length. However, there was no difference in their postoperative generic health or rate of satisfaction.

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Keywords: Hip, Arthroplasty, Robotic, Function, Satisfaction, Outcome

Article focus

- To compare the functional outcome and patient satisfaction of robotic assisted total hip arthroplasty (rTHA) with manual total hip arthroplasty (mTHA).
- To assess the radiological component positioning and restoration of leg length between rTHA and mTHA.

Key messages

- Patients undergoing rTHA had a greater postoperative hip-specific functional outcome when compared to those undergoing manual surgery.
- The Forgotten Joint Score may be the tool of choice to assess the hip specific outcome of

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rTHA due to the lower ceiling effect when compared to the Oxford Hip Score.

Strengths and limitations

- A powered propensity match cohort study.
- Short-term follow-up (mean of 10 months in rTHA group and 12 months in mTHA group) is a limitation.
- Selection bias as two different centres were used: a private hospital for rTHA and the NHS for mTHA.

Introduction

Despite total hip arthroplasty (THA) being declared the operation of the last century, offering good functional outcome and high satisfaction rates, robotic assisted surgery has the potential to enhance the outcome further.^{1,2} Robotic assisted (r)THA has progressed since the original ROBODOC surgical system (THINK Surgical, Fremont, California, USA) was first introduced in 1992, which is a fully active system (independent of surgeon).³ CASPAR (Universal Robot Systems, Rastatt, Germany) was subsequently released and was also a fully active system but is no longer available.² The MAKO Robotic arm Interactive Orthopaedic (RIO) system (Stryker, Kalamazoo, Michigan, USA) is different from ROBODOC and CASPAR as it is a semi-active system (surgeon required), and was first used to perform rTHA in 2010 with subsequent Food and Drug Administration (FDA) approval in 2015.² There is a growing body of evidence demonstrating that rTHA improves accuracy in positioning of the components when compared to manual (m)THA, but it is not clear whether there is any functional benefit of rTHA over mTHA.⁴⁻⁶

There have been three meta-analyses recently, which have all concluded that rTHA offers improved accuracy of component alignment and restoration of leg length, but no difference in functional outcome was observed when compared to mTHA.⁴⁻⁶ However, all three of these meta-analyses focussed on fully active systems with the inclusion of only one study using a semi-active system by Bukowski et al,⁷ which showed that patients undergoing rTHA had a significantly better hip-specific function when compared to those undergoing mTHA. Domb et al⁸ have subsequently published a similar comparative study using the same semi-active system for their rTHA group, which also found a better hip-specific function compared to mTHA. However, the comparative study by Bukowski et al⁷ was retrospective and the matched cohort study by Domb et al⁸ did not account for preoperative function or general health of the patients. It is not clear from the current evidence whether semi-active rTHA offers a greater hip-specific outcome when adjusting for patient demographics and preoperative level of function when compared to mTHA.

The primary aim of this study was to compare the hip-specific functional outcome of rTHA with mTHA

for the management of end stage osteoarthritis (OA) of the hip. Secondary aims were to compare general health improvement, patient satisfaction, and radiological component position and restoration of leg length between rTHA and mTHA.

Methods

Ethical approval was obtained from the regional ethics committee (Research Ethics Committee, South East Scotland Research Ethics Service, NHS Scotland, UK; 16/SS/0026) for collection, analysis, and publication of the anonymized data for the mTHA cohort. Approval from the hospital was also obtained for use of the data for the rTHA cohort as part of ongoing assessment of a new surgical process.

Patients. Patients were recruited from two centres and underwent THA by the same surgeons; one private centre (Spire Murrayfield Hospital, Edinburgh, UK) offered rTHA and in the other NHS centre (Royal Infirmary of Edinburgh, Edinburgh, UK) only mTHA was performed. Inclusion criteria included OA of the hip (complete radiological joint space loss). Exclusion criteria included the following: inflammatory arthritis; haemochromatosis; chondrocalcinosis; or haemophilia, immobility, or other neurological conditions affecting musculoskeletal function. A consecutive series of 71 patients undergoing rTHA from one centre over a 20-month period (November 2017 to June 2019) had prospective data collected. At the other centre 512 patients underwent mTHA for OA over a 12-month period. Postoperative outcome data were available for 40 (56%) of the 71 rTHA patients; there was no difference in the preoperative demographic or functional measures between the study cohort and those lost to follow-up (Table I).

Propensity score matching was used to derive a matched mTHA group for comparison of outcomes with the rTHA group. This technique is thought to offer a more accurate matching for case-control comparison and aims to match patients over a wider range of baseline characteristics.⁹ First a 'propensity score' is calculated, which represents the chances of being in the rTHA group compared with the mTHA group. The score is derived from a multivariate logistic regression model based on several baseline characteristics. The variables selected for this study were age at operation, sex, body mass index (BMI), American Society of Anesthesiologists (ASA) grade,¹⁰ and preoperative functional scores. The rTHA group was the base group and the closest matching controls (according to their propensity score) from the mTHA group were selected. As a 1:2 ratio was used to power the study, the final study cohort yielded 40 in the rTHA group and 80 in the mTHA group.

Preoperative planning. All surgeons (PG, PS, GM, JTP) performed preoperative templating on all patients using standing plain anteroposterior pelvic radiographs using digital software (picture archiving and communication system; Eastman Kodak Company, Morristown, New

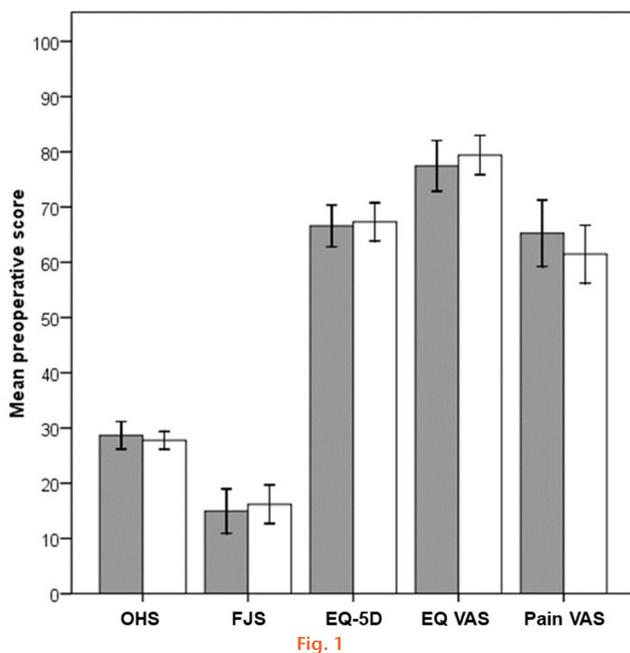
Table 1. Patient demographics and preoperative functional scores for study cohort and those lost to follow-up.

Demographic	rTHA		OR/Diff	95% CI	p-value
	Study cohort (n = 40)	Lost to FU (n = 31)			
Sex, n (% of group)					
Male	28 (70.0)	22 (71.0)	OR 1.05	0.37 to 2.93	0.920*
Female	12 (30.0)	9 (29.0)			
Mean age, yrs (SD)	59.8 (7.5)	59.6 (10.0)	Diff 0.2	-4.1 to 4.4	0.930†
Mean preoperative PROM (SD)					
OHS	28.8 (7.7)	27.7 (7.2)	Diff 1.2	-2.4 to 4.8	0.512†
FJS	15.7 (13.2)	13.9 (9.7)	Diff 1.8	-3.8 to 7.5	0.522†
EQ-5D	0.669 (0.117)	0.618 (0.162)	Diff 0.051	-0.016 to 0.117	0.132†
EQ VAS	77.5 (14.1)	70.7 (18.6)	Diff 6.8	-1.0 to 14.6	0.086†
Pain VAS	65.3 (18.6)	55.1 (24.3)	Diff 10.2	-0.1 to 20.4	0.051†

*Chi-squared test.

†Independent-samples *t*-test.

CI, confidence interval; Diff, difference; EQ-5D, EuroQol five-dimension questionnaire; EQ VAS, EuroQol visual analogue scale; FJS, Forgotten Joint Score; FU, follow-up; OHS, Oxford Hip Score; OR, odds ratio; PROM, patient-reported outcome measure; rTHA, robotic assisted total hip arthroplasty; VAS, visual analogue scale.



Preoperative patient-reported outcome measures for the robotic assisted total hip arthroplasty (rTHA) (grey) and manual total hip arthroplasty (mTHA) (white) groups. Error bars represent 95% confidence intervals. EQ-5D, EuroQol five-dimension questionnaire; EQ VAS, EuroQol visual analogue scale; FJS, Forgotten Joint Score; OHS, Oxford Hip Score; VAS, visual analogue scale.

Jersey, USA) on a liquid crystal display. Patients undergoing rTHA also had preoperative CT scans of the pelvis and proximal femur to aid implant positioning using patient-specific computer-aided design models using the MAKOplasty Total Hip Application system (Stryker). The aid of templating was to restore the native centre of rotation and offset using the contralateral side as reference, if normal, and to correct for any leg length discrepancy. Planned acetabular component position was 40° inclination and 20° to 30° of anteversion in both groups.

Surgical technique. During the study period four of the authors (PG, PS, GM, JTP) performed all the THAs at both centres. A posterior approach to the hip joint was utilized in all patients. For those undergoing rTHA, registration pins were placed in the pelvis and proximal femur onto which the arrays were mounted, and computer registration was performed by mapping of prespecified anatomical landmarks. Patients undergoing rTHA received an uncemented Trident Acetabular Shell (Stryker) with a highly crosslinked polyethylene liner. Patients undergoing mTHA received a cemented crosslinked contemporary acetabular component (Stryker, Newbury, UK). All patients received a cemented Exeter stem (Stryker), which was inserted using third-generation cementing techniques. All patients received systemic prophylactic antibiotics (1.5 g cefuroxime) before surgery.

Outcomes. Preoperative and postoperative functional outcomes were obtained prospectively. The Oxford Hip Score (OHS),¹¹ Forgotten Joint Score (FJS),¹² EuroQol five-dimension questionnaire (EQ-5D),¹³ EuroQol visual analogue scale (EQ VAS),¹³ and levels of pain and patient satisfaction with their hip were assessed. The OHS, FJS, EQ-5D, EQ VAS, and level of pain were assessed pre- and postoperatively, and level of patient satisfaction was assessed postoperatively only. Postoperative outcomes were assessed at six months' follow-up in the nine patients who underwent rTHA, and all other outcomes data were assessed at 12 months' postoperative follow-up.

The OHS is a hip-specific score and was used as the primary outcome measure. This score consists of 12 questions assessed on a Likert scale with values from 0 to 4; a summative score is then calculated where 48 is the best possible score (least symptomatic) and 0 is the worst possible score (most symptomatic).¹¹ The OHS has a defined minimal clinically important difference of five points.¹⁴ The FJS assesses joint awareness during the activities of daily living (for example, climbing stairs, walking for more than 15 minutes, in bed at night, etc).¹²

Table II. Patient demographics and preoperative functional scores according to group.

Demographic	Group		OR/Diff	95% CI	p-value
	rTHA (n = 40)	mTHA (n = 80)			
Sex, n (% of group)					
Male	28 (70.0)	54 (67.5)	OR 1.12	0.49 to 2.56	0.781*
Female	12 (30.0)	26 (32.5)			
Mean age, yrs (SD)	59.8 (7.5)	60.0 (11.7)	Diff 0.2	-3.8 to 4.3	0.907†
Mean BMI, kg/m ² (SD)	30.1 (4.6)	30.2 (5.3)	Diff 0.1	-4.2 to 4.4	0.890†
ASA grade, n (% of group)					
1	20 (50.0)	32 (40.0)	Reference		
2	19 (47.5)	45 (56.3)	OR 1.5	0.7 to 3.2	0.320*
3	1 (2.5)	3 (3.8)	OR 1.9	0.2 to 19.3	0.999*
Mean preoperative PROM (SD)					
OHS	28.8 (7.7)	27.8 (7.3)	Diff 1.1	-1.8 to 3.9	0.460†
FJS	15.7 (13.2)	16.2 (15.7)	Diff 0.5	-5.3 to 6.2	0.460†
EQ-5D	0.669 (0.117)	0.673 (0.156)	Diff 0.004	-0.051 to 0.059	0.883†
EQ VAS	77.5 (14.1)	79.4 (16.0)	Diff 2.0	-4.0 to 7.9	0.518†
Pain VAS	65.3 (18.6)	61.5 (23.6)	Diff 3.8	-4.8 to 12.3	0.383†
Mean length of follow-up, mths (SD)	10.6 (2.2)	12.1 (0.3)	Diff 1.5	-0.5 to 2.5	0.001†

*Chi-squared test.

†Independent-samples *t*-test.

ASA, American Society of Anesthesiologists; BMI, body mass index; CI, confidence interval; Diff, Difference; EQ-5D, EuroQol five-dimension questionnaire; EQ VAS, EuroQol visual analogue scale; FJS, Forgotten Joint Score; mTHA, manual total hip arthroplasty; OHS, Oxford Hip Score; OR, odds ratio; PROM, patient-reported outcome measure; rTHA, robotic assisted total hip arthroplasty; VAS, visual analogue scale.

It consists of 12 questions assessed using a five-point Likert response format. Item scores are summed and transformed to a 0 to 100 scale, a high value reflecting the ability of the patient to forget about the affected/replaced joint during the activities of daily living. There is no agreed minimum clinically important difference in the FJS after THA currently, so half the SD was used to define this.¹⁵ The EQ-5D was used, which measures five domains (mobility, self-care, usual activities, pain/discomfort, and anxiety/depression) according to three levels (3 L) of severity (no problems, some problems, or extreme problems).¹³ An individual patient's health state can be reported based on the five-digit code for each domain, of which there are 243 possible health states (ranging from -0.56, which is worse than death, to 1.0 being perfect health). The EQ VAS was assessed, which records the patient's self-rated health on a vertical visual analogue scale (VAS), where the endpoints are labelled 'The best health you can imagine' (100) and 'The worst health you can imagine' (0). The VAS can be used as a quantitative measure of health outcome that reflects the patient's own judgement. A VAS of 0 (worst pain) to 100 (no pain) was also used to assess pain.

Patient satisfaction was assessed by asking the question "How satisfied are you with your operated hip?". The response was recorded using a five-point Likert scale: 'very satisfied', 'satisfied', 'neither', 'dissatisfied', or 'very dissatisfied'. Patients who recorded 'very satisfied' or 'satisfied' were classified as 'satisfied'. This has been

used previously to assess patient satisfaction after THA.¹⁶ Patients were also asked: "Would you have this operation again if it was required on another joint?". The response was recorded using a five-point Likert scale: 'extremely likely', 'likely', 'neither', 'unlikely', or 'extremely unlikely'. In addition, a sixth option of 'don't know' was possible.

Radiological assessment was performed by a single observer (NDC) using a standardized anteroposterior radiograph of the hip or pelvis and hips preoperatively and postoperatively. All measurements were made using digital radiographs (Eastman Kodak Company) picture archiving and communications systems on a liquid crystal display and the graphic measuring tools available. The measuring calibration tool was used to ensure that equal measures were obtained. Magnification was corrected on postoperative radiographs using the implanted acetabular component size as the reference value.¹⁷ The postoperative radiograph was used to calculate the contralateral femoral head size, and this was used as the reference for correcting magnification on the preoperative radiograph. Radiological measurement of offset and length for both the femoral and acetabular components were measured according to the methods described by Nunn et al¹⁸ and Jolles et al.¹⁹ Loughhead et al²⁰ have demonstrated excellent inter- and intra-observer reliability/correlation in these radiological measurements. Femoral offset, length, acetabular offset, and height were defined as described by Clement et al.²¹ Accuracy in achieving the planned centres of horizontal and vertical rotation

Table III. Postoperative outcome measures and the difference between groups.

Functional measure	rTHA		mTHA		Difference	95% CI	p-value*
	Mean	SD	Mean	SD			
OHS	44.4	5.0	41.9	6.6	2.5	0.1 to 4.8	0.038
FJS	78.0	24.2	56.9	28.0	21.1	10.7 to 31.5	< 0.001
EQ-5D	0.883	0.150	0.866	0.157	0.017	-0.042 to 0.077	0.562
EQ VAS	88.6	9.5	86.1	15.0	2.4	-2.7 to 7.6	0.355
Pain VAS	88.9	16.1	85.5	21.4	3.5	-4.1 to 11.1	0.370

*Independent-samples *t*-test.

EQ-5D, EuroQol five-dimension questionnaire; EQ VAS, EuroQol visual analogue scale; FJS, Forgotten Joint Score; mTHA, manual total hip arthroplasty; OHS, Oxford Hip Score; rTHA, robotic assisted total hip arthroplasty; VAS, visual analogue scale.

were assessed using the method described by Meermans et al.²² Acetabular component inclination²³ and version²⁴ were calculated from anteroposterior radiographs of the hip and/or hip and pelvis using established and validated techniques.²⁵ The safe zones for acetabular component positioning were assessed using the commonly adopted parameters defined by Lewinnek et al²⁶ (inclination of 30° to 50° and anteversion of 5° to 25°) and Callanan et al²⁷ (inclination of 30° to 45° and anteversion of 5° to 25°). Leg length discrepancy was defined as the distances from the vertex of the lesser trochanters to a line transecting through the inferior aspect of the acetabular teardrops as described by Woolson et al.²⁸

Statistical analysis. Data analysis was performed using SPSS v17.0 (SPSS, Chicago, Illinois, USA). Parametric and non-parametric tests were used as appropriate to assess continuous variables for significant differences between groups. Unpaired (independent-samples) and paired *t*-tests were used to compare linear variables between groups. Dichotomous variables were assessed using a chi-squared test and a Fisher's exact test if there were less than five in any cell. A *p*-value of < 0.05 was defined as significant.

A power calculation was performed using the OHS (primary outcome measure), which has a defined minimal clinically important difference of five points¹⁴ and a SD of nine points.²⁹ A 1:2 ratio was used due to the smaller number of rTHAs performed relative to mTHAs. This determined that a minimum of 39 patients in the rTHA group and 79 patients in the mTHA group would achieve a power of 0.80 using two-tailed analysis (assumed better outcome in rTHA) and an α of 0.05.

Results

After propensity score matching, the two groups were similar, with no statistically significant differences in patient demographics, BMI, ASA grade, or preoperative functional scores (Table II and Figure 1). Mean length of follow-up was significantly shorter (10.6 months (SD 2.2)) in the rTHA group compared to the mTHA group (12.1 months (SD 0.3)) due to the nine patients in the rTHA only having six-month data available. There were no postoperative complications in the rTHA group. However, one patient in the mTHA group developed a deep vein thrombosis on day three postoperatively, who subsequently had wound problems due to anticoagulation

which subsequently settled with a negative pressure dressing, making an uneventful recovery.

Functional outcome. The rTHA group had a significantly greater postoperative OHS of 2.5 points (95% confidence interval (CI) 0.1 to 4.8; *p* = 0.038, independent-samples *t*-test) compared to the mTHA group (Table III and Figure 2), but this was less than the minimal clinically important difference of five points.¹⁴ In contrast, the FJS was not only statistically significantly greater in the rTHA group compared to the mTHA group but the difference of 21.1 points (95% CI 10.7 to 31.5; *p* < 0.001, independent-samples *t*-test) was also clinically significant (Table III and Figure 2), being greater than 14 points (half the SD). In addition, there was a smaller SD observed in the OHS and FJS for the rTHA group relative to the mTHA group, which suggests a tighter and more reliable distribution of outcome scores. There was a trend towards higher (better) postoperative generic health EQ-5D score, EQ VAS, and pain VAS for the rTHA group compared to the mTHA but these were not statistically significant (Table III and Figure 2).

Satisfaction. One patient from the rTHA group and one patient from the mTHA group did not answer their satisfaction question or whether they would have the operation again. No patient was dissatisfied with their rTHA and six patients were dissatisfied with their mTHA, but this was not statistically significant (Table IV). One patient in the rTHA group and five in the mTHA group replied unsure to the question as to whether they would have surgery again. There were no patients in the rTHA group who would not have the operation again whereas five (6.3%) would not have the operation again in the mTHA group, but this was not significant (Table IV).

Radiological assessment. There was a significant (*p* < 0.001, independent-samples *t*-test) decrease in the horizontal centre of rotation for the mTHA group when compared to the rTHA group, which was also associated with a decrease in acetabular offset. However, the vertical centre of rotation was not significantly different (*p* = 0.132, independent-samples *t*-test) (Table V). The overall combined offset was not significantly different between the groups, however there was a significant (*p* < 0.001, independent-samples *t*-test) decrease in acetabular offset and increase in femoral offset observed in the mTHA group compared to the rTHA group (Table V). There was no significant difference in the accuracy of component

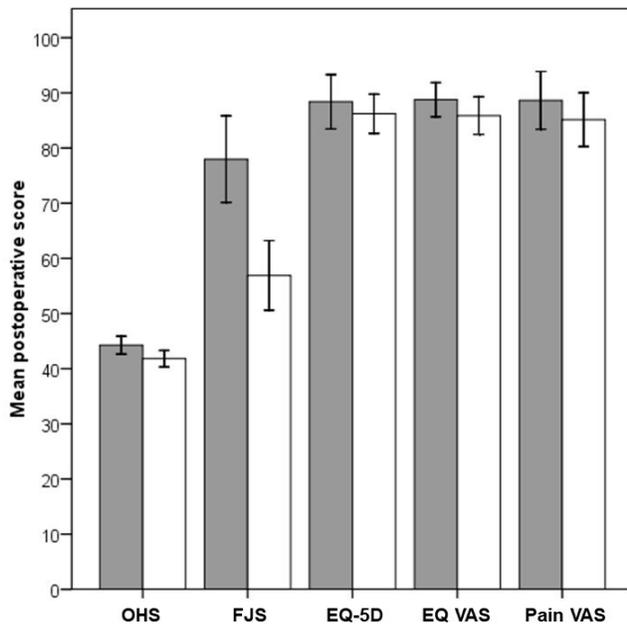


Fig. 2

Postoperative patient-reported outcome measures for the robotic assisted total hip arthroplasty (rTHA) (grey) and manual total hip arthroplasty (mTHA) (white) groups. Error bars represent 95% confidence intervals. EQ-5D, EuroQol five-dimension questionnaire; EQ VAS, EuroQol visual analogue scale; FJS, Forgotten Joint Score; OHS, Oxford Hip Score; VAS, visual analogue scale.

inclination, whereas there was a significantly greater rate of accuracy for component anteversion and overall alignment for the rTHA group compared to the mTHA group (Table V). Although mean leg length was increased in the rTHA group (2.3 mm (SD 3.0)), it was significantly greater (difference 3.6 mm, 95% CI 2.0 to 5.2, $p < 0.001$, independent-samples *t*-test) in the mTHA group (mean 5.9 mm (SD 6.0)) (Table V).

Discussion

This study has demonstrated a significantly greater postoperative hip-specific functional outcome for patients undergoing rTHA when compared to mTHA for OA of the hip. However, there was no significant difference in the postoperative general health or subjective hip pain between rTHA and mTHA. There was a trend towards a greater rate of patient satisfaction and willingness to undergo surgery again in the rTHA group, but this did not reach statistical significance. Robotic assisted THA was associated with greater accuracy of acetabular component positioning and restoring centre of hip rotation and leg length.

The major limitation of this study was the non-randomization of the patients to rTHA or mTHA groups, which was dependent on which hospital they presented to. The four surgeons (PG, PS, GM, JTP) performing all the THAs included in the study work between the two hospitals, but rTHA is not available in one of the hospitals and patients in that institution undergo

Table IV. Postoperative satisfaction according to group (one patient from each group did not respond to their question).

Question	Response	Group, n (%)		p-value*
		rTHA	mTHA	
Are you satisfied with your hip?	Yes	39 (100)	73 (92.4)	0.176
	No	0	6 (7.6)	
Would you have this surgery again?	Yes	38 (97.4)	69 (87.3)	0.165
	No	0	5 (6.3)	
	Unsure	1 (2.6)	5 (6.3)	

*Fisher's exact test two-tailed.

mTHA, manual total hip arthroplasty; rTHA, robotic assisted total hip arthroplasty.

mTHA. Propensity score matching was used to match for preoperative demographics, hip-specific function, and general health, which is a novel aspect of this study relative to other studies comparing rTHA with mTHA using a semi-active system.^{7,8} The relatively short length of follow-up at a mean 10 months (SD 2.2) is another limitation and with longer follow-up the hip-specific scores may continue to improve, however this may be marginal with little change being observed from 12 to 96 months after mTHA.³⁰ The 1:2 group ratio could also be raised as a limitation of the study. This ratio was chosen because of the availability of data from the two centres included, with the centre performing rTHA being a smaller volume centre relative to the larger volume centre performing mTHA. However, one advantage of the larger number of mTHAs was the ability to propensity score match to the smaller defined rTHA group, which enabled a powered comparative study to be conducted. The propensity score matching did not include patient comorbidities, which is a limitation, but did include the EQ-5D which is a marker of generic physical and mental health.³¹

The results of the current study support that of the previous two comparative studies by Bukowski et al⁷ and Domb et al,⁸ demonstrating greater hip-specific function after semi-active rTHA when compared to mTHA. Bukowski et al⁷ demonstrated a significantly greater (better) modified Harris Hip Score³² in their rTHA cohort relative to the mTHA cohort, but the difference they found of eight points may not be clinically significant.³³ This is similar to the current study when assessing hip function using the OHS, which was significantly better postoperatively in the rTHA group but not greater than the minimal clinically important difference of five points. However, it has been suggested that the minimal clinically important difference in the OHS may be as low as two to three points, which would support a clinically significant difference in the current study.³⁴ Domb et al⁸ demonstrated a similar postoperative FJS of 82 points, compared to the current study of 78 points, in their rTHA group. This relatively high postoperative FJS observed for rTHA is supported by the cohort reported

Table V. Radiological assessment of robotic assisted total hip arthroplasty versus manual total hip arthroplasty for component position and accuracy of alignment according to Lewinnek's and Callanan's criteria.

Radiological assessment	rTHA	mTHA	OR/Diff (95% CI)	p-value
Mean horizontal centre of rotation, mm (SD)	0.2 (1.3)	-2.2 (4.5)	Diff: 2.4 (1.3 to 3.3)	< 0.001*
Mean vertical centre of rotation, mm (SD)	0.3 (0.9)	-0.1 (2.0)	Diff: 0.4 (-0.1 to 0.9)	0.132*
Mean combined offset, mm (SD)	0.5 (2.9)	1.0 (3.8)	Diff: 0.5 (-0.7 to 1.7)	0.419*
Mean acetabular offset, mm (SD)	0.2 (1.1)	-2.1 (4.4)	Diff: 2.3 (1.3 to 3.3)	< 0.001*
Mean femoral offset, mm (SD)	0.3 (1.6)	3.1 (4.0)	Diff: 2.8 (1.6 to 4.0)	< 0.001*
Mean leg length, mm (SD)	2.3 (3.0)	5.9 (6.0)	Diff: 3.6 (2.0 to 5.2)	< 0.001*
Component inclination, n (% of group)				
Lewinnek's safe zone	38 (95.0)	65 (81.3)	OR: 4.3 (1.0 to 20.2)	0.052†
Callanan's safe zone	37 (92.5)	62 (77.5)	OR: 3.6 (1.0 to 13.0)	0.072†
Component anteversion, n (% of group)				
Lewinnek's safe zone	39 (97.5)	67 (83.8)	OR: 7.6 (1.0 to 60.1)	0.033†
Callanan's safe zone	39 (97.5)	65 (81.3)	OR: 9.0 (1.1 to 70.8)	0.020†
Overall component position, n (% of group)				
Lewinnek's safe zone	38 (95.0)	55 (68.8)	OR: 8.6 (1.9 to 38.6)	0.002†
Callanan's safe zone	37 (92.5)	53 (66.3)	OR: 6.3 (1.8 to 22.3)	0.003†

*Independent-samples *t*-test.

†Fisher's exact test.

CI, confidence interval; Diff, difference; mTHA, manual total hip arthroplasty; OR, odds ratio; rTHA, robotic assisted total hip arthroplasty.

by Perets et al,³⁵ who found the FJS to be 83 points two years after rTHA while also using a semi-active system. The postoperative FJS of 57 points demonstrated for the mTHA group in the current study is also consistent with the results of other studies reporting the 12-month postoperative FJS.^{36,37} Therefore the 21-point greater postoperative FJS seen in the rTHA group relative to the mTHA group is consistent with other studies, and represents a clinically significant benefit of rTHA.

The reason why there was a clinically significant difference in the FJS and not in the OHS between rTHA and mTHA may relate to the intrinsic properties of these scoring measures. The mean postoperative OHS for the rTHA group was within four points of the maximum score of 48, which suggests there may be a ceiling effect when using the OHS to measure functional outcome after rTHA. Hamilton et al³⁸ have previously shown the OHS to be predominantly a measure of preoperative hip-specific dysfunction and is blunted to higher levels of performance observed postoperatively. Therefore, the OHS may not have the measurement range or sensitivity to differentiate between well-performing groups postoperatively. In contrast, the FJS has a greater postoperative measurement range due to the low postoperative ceiling effect and twice the effect size of the OHS.³⁸ Despite the high FJS after rTHA observed in the current study and by other studies of approximately 80 points,^{8,35} this is lower than the expected normal age-matched FJS in a population without a THA of approximately 90 points,³⁹ which suggests there may still be room for improvement.

The rate of satisfaction after mTHA is reported to be between 88% and 93%,^{40,41} which is similar to the reported rate of 92% for the mTHA assessed in the current study. In contrast, the rate of satisfaction in the rTHA group was 100%, although this was not a significant difference due to the small cohort assessed. The reason why the satisfaction rate was greater in the rTHA group is not clear but is supported by its significantly greater mean postoperative FJS.³⁷ Satisfaction has been assessed by other studies for semi-active rTHA, but they used a satisfaction VAS and did not declare rates for categorical satisfaction and dissatisfaction.^{7,8}

One explanation of the observed improved outcomes associated with the rTHA group over the mTHA group may relate to the improved accuracy demonstrated in acetabular alignment, restoration of hip centre and leg length. Kayani et al¹⁷ demonstrated a similar finding with improved implant position accuracy with rTHA compared to mTHA. Nodzo et al⁴² have demonstrated that the intraoperative component position defined by rTHA correlates with that assessed postoperatively on CT scanning. However, it is only more recently that Domb et al⁸ also showed improved functional outcomes that were also associated with a greater accuracy of component positioning in the rTHA group over mTHA. The improved accuracy in component positioning may also be associated with improved implant survival in the mid to longer term.⁴³

Data from the American healthcare system suggested that rTHA is cost-effective when compared to standard of care mTHA.⁴⁴ Whether the additional cost of the

preoperative CT scan and the robot to perform rTHA will be cost-effective in the UK's NHS is not yet known. However, if there is a lower rate of complications such as dislocation as current data suggest,^{7,45} in addition to the improved functional outcome this may negate the increased costs of robotic surgery. This should be an area of future research to assess whether the improved functional outcome is cost-effective.

In conclusion, patients undergoing rTHA had a greater hip-specific functional outcome when compared to mTHA, however there was no difference in their generic health or rate satisfaction. Whether the early functional benefits of rTHA over mTHA are cost-effective and observed into the mid to longer term needs to be assessed. The FJS may be the tool of choice to assess the hip-specific outcome of rTHA due to the lower ceiling effect when compared to the OHS.

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